IMBIBITION TEST OF ENHANCED OIL RECOVERY BY USING NANOPARTICLES (SPINAL OXIDE)

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ABSTRACT:

There are three types of energy operations for oil production, primary recovery, secondary recovery and Enhanced oil recovery (EOR). EOR is the final stage of production operations. Where the EOR is classified into several types such as gas injection, thermal injection, microorganism and chemical flooding. Chemical flooding has different types such as polymer, surfactant, alkaline and nanoparticles. Generally, Nanoparticles in petroleum industry has been considered very contributing due to it is ability to increase the oil recovery and assist the conventional methods.

The aim of the study is to investigate the impact of Cobalt ferrite oxide $CO(Fe_2O_4)$ from rock with different concentration at 0.49 %, 0.99%, and 1.47% % at different temperatures and compared with the distilled water. The temperature gradually changed every 24 hours started at room temperature to oven temperature (25Co,30Co, 50Co, 70Co).

The results have shown that the oil recovery at concentration 0.49%, 0.99%, 1.47% and distilled water were 48.3%, 24%,67.6 % and 90 % respectively. The highest oil recovery was when distilled water was used, the recovery factor was (90%). Thus the highest recovery factor due to the high permeability samples, also nanoparticles $CO(Fe_2O_4)$ may cause plugging phenomena. More investigation are currently running at China University of petroleum to deeply investigate the effect of $CO(Fe_2O_4)$ on the nanoparticles. this work represents the first work in this material but it is not the last.

Keywords: Distilled water; Cobalt ferrite oxide; Sandstone reservoir; Imbibition test.

1. INTRODUCTION

Enhanced oil recovery (EOR) refers to any reservoir process used to change the existing rock/oil/brine interactions (fluid/fluid interaction; fluid/rock interaction) in the reservoir in order to increase the oil recovery, and this interaction might reduce the interfacial tension, oil swelling, reduce oil viscosity; also wettability modification[1].

As well known, the EOR has different method and every method has it is criteria to use it. One of those method is chemical nanoparticles. Indeed, application of chemical nanoparticles in the oil and gas industry is just emerging. Recent research projects have shown that nanotechnology has the potential to solve or manage several problems in the petroleum industry. One of the speculated areas of application is in Enhanced Oil Recovery (EOR). Clearly, the ability of nanoparticles to alter certain factors in the formation and in oil properties can be taken advantage to enhance the recovery. This involves introducing these nanoparticles into formations and studying its effect on oil recovery.[2]

Generally, previous studies have reported that the nanoparticles have been used to test their ability to enhance the oil recovery. Although, some of those nanoparticles have reported to be able to enhance the oil recovery such as Aluminium oxide (Al_2O_3), Nickel and Iron oxides etc. On the other hand, some of nanoparticles have failed due to plugging the pores such as Magnesium oxide

and Zinc oxide [3,4]. $CO(Fe_2O_4)$ have not been used to test the recovery factor. This is the first study about the $CO(Fe_2O_4)$ in EOR process.

$CO(Fe_2O_4)$ has been used in the oil industry as an oil absorbent material with the aim of removing crude oil and its derivatives from aqueous solutions [5]. The ability of $CO(Fe_2O_4)$ to absorb the oil give us a big motivation to use this material to enhance the oil recovery. Many challenges and techniques (stability and performance and displacement efficiency) need to investigate the ability of this material to enhance the oil recovery.

As well known, The nanoparticles are solids and as such need a dispersing agent to carry them into the formation, the contribution of the dispersing agents in displacing oil could be mistaken for or attributed to the presence of the Nano agent[3]. Different dispersing agent have been used with nanoparticles such as brine, distilled water, ethanol and diesel. Although, some types of Nanoparticles such as hydrophobic silicon oxide nanoparticles cannot dispersed in polar fluids such as brine and distilled water. Hydrophobic silicon oxide nanoparticles can be dispersed in organic fluids such as ethanol and diesel [4].

The dispersing agent is a significant role in oil displacement efficiency. To overcome the stability issues, the surface of the nanoparticles can be modified by attaching or coating macro-molecules (e.g., polymers) on NPs surface on it, or new functionalities (silane coupling agents) may be given to the surface of the NPs to prevent them from attracting each other or with the surrounding molecules [6].

Moreover, the nanoparticles have been used as assistant agent to assist the conventional method such as surfactant and polymer. In last few years, several work have been done to reduce the surfactant adsorption by the addition of different additives. For instance, the addition of nanoparticles can help to reduce the diffusion and the adsorption of surfactant. This is due to their small size compared to micellar structures and dissolved species which help them to be transported through reservoir rocks with minimum retention on pore walls [7]. Also, in polymer flooding, adding silica nanoparticles to polymer solution can be an acceptable method to enhance oil recovery because besides increasing sweep efficiency by means of polymer, nanoparticles which are present in polymer solution can alter the surface wettability. Thus, the flooding will increase both the microscopic and macroscopic displacement efficiency.

2. CONSTITUENT MATERIALS AND EXPERIMENTS

2.1 Experiment Materials

- Core Sample (Figure 1.a);
- Crude Oil Sample 0.8737g/cc, Figure 1.b;
- Distillated Water, Figure 1.c;
- Cleaning Solvent, Toluene, Figure 1.d;

Figure 1. Experimental Materials Used in this Study.

Table 1. The Composition of Crude Oil.

Peak Name	Result %	Peak Name	Result %
C3	0.0199	C20	2.5313
i-C4	0.0226	C21	1.8426
n-C4	0.1086	C22	1.7675
i-C5	0.2284	C23	1.5543
n-C5	0.3876	C24	1.2628
C6	2.9209	C25	1.2702
C7	4.2509	C26	1.0971
C8	7.0064	C27	0.9924
C9	7.0334	C28	1.0820
C10	6.8777	C29	1.5831
C11	7.0009	C30	2.1104
C12	5.5290	C31	2.5186
C13	6.3112	C32	1.8193
C14	6.5397	C33	1.3606
C15	5.9047	C34	0.4582
C16	4.3228	C35	0.2137
C17	3.7374	C36	0.1573
C18	4.1664	C37	0.0960
C19	3.7098	C38+	0.1987

Table 2. The Properties of Crude Oil.

Test Method	Test Description	Result X-Field	Unit
ASTM D 5002	Density @15C°	0.8245	g/cc
	Sp.Gr @ 60/60F°	0.8249	
	API	40	
ASTM M D 445	K.Viscosity@25C°	5.6136	mm^2/s
	K.Viscosity@37.5C°	3.5915	

2.2 Experiment Machines and Tools

- Plugging Machine (drill samples) (Figure 2.a);
- Trimming Saw (Figure 2.b);
- Oven Memmert (30 °C to 700 °C) (Figure 2.c);
- Soxhcelete Extractor Device (Figure 2.d);
- Digital Balance (Figure 2.e);
- Vacuum Pump (Figure 2.f);
- Vacuum Chamber (Figure 2.g);
- Cup (Figure 2.h);
- Inhibition Cell (Figure 2.i);
- Vernier Caliper (Figure 2.j)
- Burning Crucible (Figure 2.k)
- Filtring Papers (Figure 2.l)
- Marienfield Mixer & Heater (Figure 2.m)
- Burning Furnace (Figure 2.n)
- Aluminuim Foil (Figure 2.o)

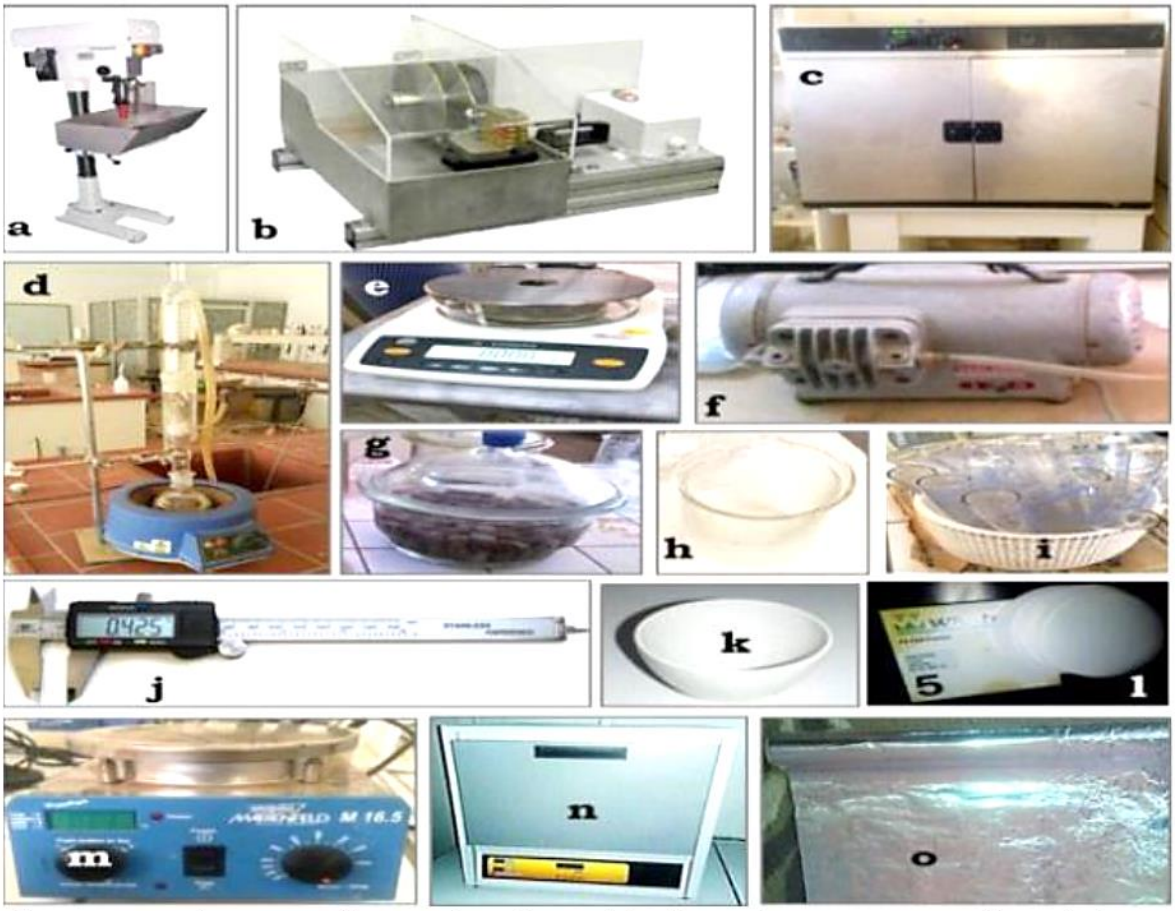

Figure 2. Experiment Machines and Tools Used in this Study 2.3 Water & Oil Analysis

2.3.1 Water Density Measurements Procedures

i. As shown in the (Figure 3.a), we use a pycnometer with volume (50 cc) in order to measure the water density;

ii. The empty pycnometer was weighted as shown on (Figure 3.b);

iii. Filling the pycnometer with water;

iv Weightening the pycnometer including water as showing in (Figure 3.c);

v. Subtract weight of pycnometer without water from weight the pycnometer with water to get water weight.

vi. The density of water was calculated according to the following equation:

$\rho w = Ww / Vw$

Where, ρw: Density of water (g/cc), Ww: Weight of water (g), and Vw: Volume of water (cc).

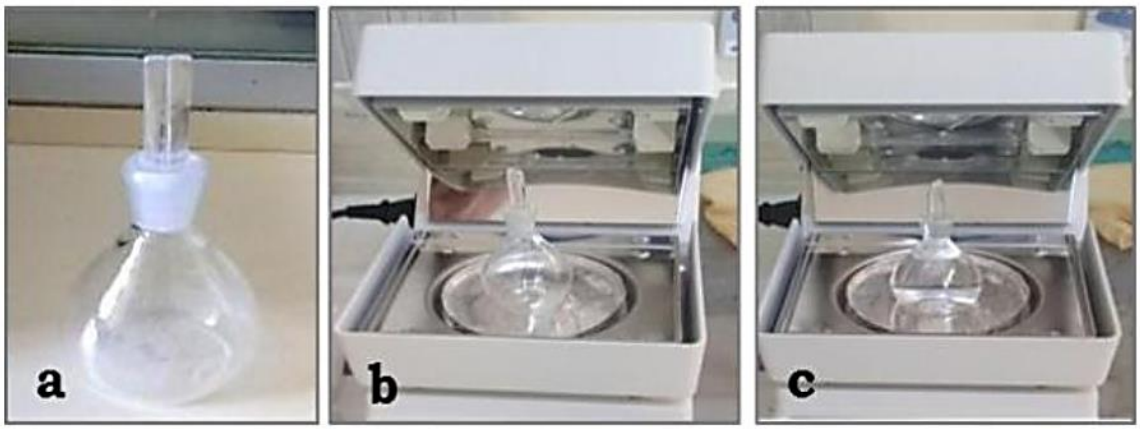

Figure 3. Water Density Measurements Procedure Used in this Study.

2.3.2 Water Density Measurements Procedure

i. As shown in the (Figure 4.a), we use a pycnometer with volume (50 cc) in order to measure the oil density;

ii. The empty pycnometer was weighted as shown on (Figure 4.b);

iii. Filling the pycnometer with oil;

iv. Weightening the pycnometer with including oil as showing in (Figure 4.c);

v. Subtracting the weight of pycnometer

without oil from the weight of

pycnometer with oil to get oil weight.

vi. The density of oil was calculated according to the following equation: $\rho o = Wo / Vo$

where, ρo: Density of oil (g/cc), Wo: Weight of oil (g), and Vo: Volume of oil (cc).

Figure 4. Oil Density Measurements Procedure

2.3.3 Core Sample Preparation Procedure

Cleaning of core sample was done in a soxhcelete device by using toluene in order to remove the oil from cores (cores was use in previous experiments and was saturated with oil). The process of cores cleaning has shown in (Figure 5.a).

2.3.4 Core Sample Drying Procedure

After core sample cleaning, we put the cores in the oven (100C0 - 120C0) in order to evaporate toluene in the pores, after 24 hours the cores were taken out of the oven and weighted then we returen back them into the oven. These steps were repeated many times until the cores weights become constant as showing in (Figure 5.b).

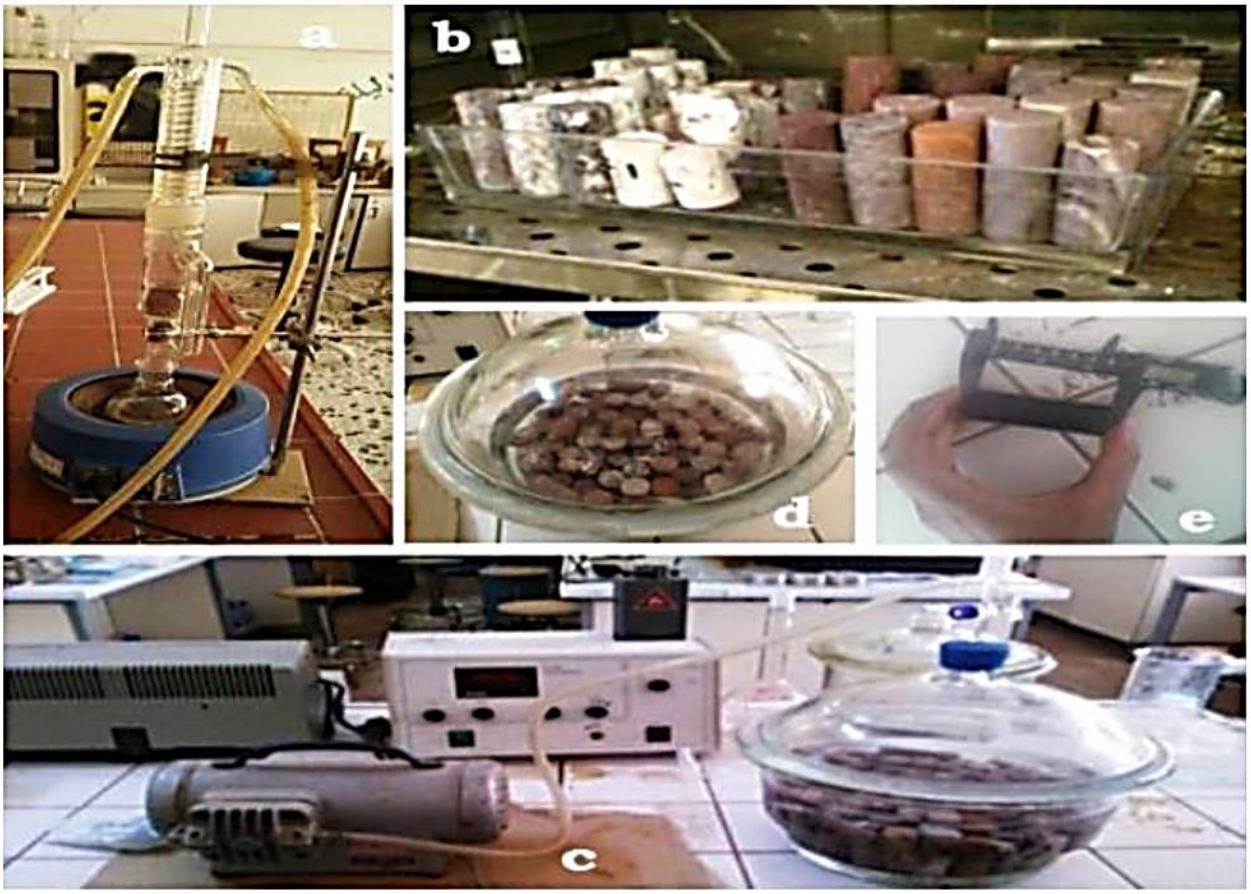

Figure 5. Clean and Saturate the Cores.

2.4 $COFe_2O_4$ Preparation

The magnetic spinal cobalt ferrite oxide powder was prepared 10 gm from magnetic spinal nanoparticle formula CFO)COFe2O4(by Sol-gel method [8], and the required quantities of cobalt nitrate (12.4041g) and iron nitrate (34.4369g) were weighed, then add it in a small amount of distilled water. Then add citric acid in amount of (36.8486g) and EDTA in amount of (37.34g) as complication factors, the ammonia solution (NH3.H2O) was added to control the pH to 6, The solution was then evaporated using an electric heater with the solution moving continuously by a magnetic mold to distribute heat.

And by continuously heating and stirring solution (mixture) to thick black gel, the magnetic stirrer was then removed and the gel left on the electric burner completely burned and turned into a solid component (ash), The component was milled solid obtained and placed in ceramic seals and burned in the air in the furnace at 600°C for 2 hours to remove the remaining organic compounds and obtain a pure phase of powder (Cobalt ferrite oxide), which will later be used as a maze material to remove the blue methylene dye from its solutions water.

3. RESULTS AND DISCUSSION

3.1 Water & Crude Oil Analysis Result

The analysis results of distilled water and oil used in experiments have shown in (Table 3 & 4).

Table 3. Distilled Water Analysis Results.

Water	W_{dry}	W_{sat}	V_w	Density
Type	(g)	(g)	(cc)	(g/cc)
Distillate water(A)	31.24	49.32	20	0.904
Distillate water(B)	29.569	82.393	50	1.0565

Table 4. Crude Oil Analysis Results.

Oil Type	W_{dry} (g)	W_{sat} (g)	V_w (cc)	Density (g/cc)
(Y) Field	29.569	73.254	50	0.8737

3.2. Core Analysis Result

3.2.1 Pore and Bulk Volume of Sandstone Core Samples Results

Table 5. Bulk Volume of Core Sandstone with Distillate Water

Name sample	Length (cm)	Diameter (cm)	Bulk Volume (cc) BV = (π/4) *D^2*L
S-002	4.96	2.91	32.9881177
S-003	6.31	2.95	43.1283926
S-005	5.07	2.88	33.0280411
S-006	4.94	2.91	32.8551011
S-007	5.07	2.91	33.7197091

Table 6. Pore Volume of Core Sandstone with Distillate Water.

Sample Name	Dry Weight W_{dry} (g)	Saturated Weight W_{sat} (g)	Weight of Amount Distillate Water (W_f) (g)	Density of Distillate Water (ρ) (g/cc)	Pore Volume (Pv) (cc) PV= W_f/ ρ
S-002	63.7521	70.491	6.7389	0.904	7.454535398
S-003	68.2248	76.7483	8.5235	0.904	9.428650442
S-005	55.6445	63.7412	8.0967	0.904	8.956526549
S-006	61.1574	68.1296	6.9722	0.904	7.712610619
S-007	59.0086	67.6425	8.6339	0.904	9.550774336

3.2.2 Porosity of Sandstone Core Samples Results with Distilled Water & Oil and Porosity of OOIP in Sandstone Core

According to results in (Tables 7), we observed that attainded minimum porosity of sandstone core sample was 21% at S-003, while the maximum one was 28% at S-007.

(Table 8) shows OOIP of sandstone core samples. Some core samples saturated in oil with density 0.8737 g/cc.

Table 7. Porosity of Core Sandstone with Distillate Water.

Sample Name	Pore Volume (cc)	Bulk Volume (cc)	Porosity $\phi = P_V / B_V$ (fra)
S-002	7.454535398	32.9881177	0.22597638
S-003	9.428650442	43.1283926	0.21861817
S-005	8.956526549	33.0280411	0.27117947
S-006	7.712610619	32.8551011	0.23474621
S-007	9.550774336	33.7197091	0.28324012

Table 8. Results of OOIP in Core Sandstone.

Sample Name	Dry Weight W_{dry} (g)	Saturated Weight W_{sat} (g)	Weight of Amount Distillate Water (W_f)(g)	Density of Distillate Water(ρ) (g/cc)	OOIP (cc)
S-002	63.7521	69.6842	5.9321	0.8737	6.7896308
S-003	68.2248	75.8667	7.6419	0.8737	8.7465949
S-005	55.6445	62.0021	6.3576	0.8737	7.27663957
S-006	61.1574	67.0269	5.8695	0.8737	6.7179819
S-007	59.0086	66.7630	7.7544	0.8737	8.8753376

3.3 FTIR Results

Functional groups on the surface of the spinel oxide prepared by the sol-gel method and then identified using the infrared absorption spectrum (FTIR). The carbon nanotube (CFO) oxide after burning the ash compounds in preparation in air at 600 ° C for two hours. Figure 6 shows the FTTR results for Nanoparticles, it is clearly seen that there are bundles of the terminals at 3968 cm-1 and 2928 cm-1; these packets can be attributed to the Co-O and Fe-O bonds, respectively. These specialty packs are characteristic of all spinel oxides.

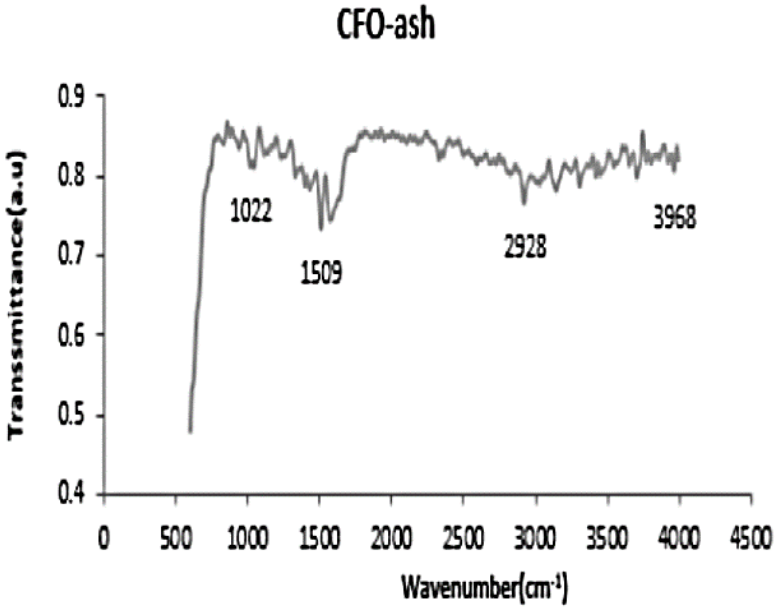

Figure 6: FTIR results for nanoparticles.

3.4. Spontaneous Imbibition Test Results

3.4.1 Effect of Nanoparticles CO(Fe2O4), With Time, and Temperature on oil Recovery for Core Sample

- **1St Scenario at Concentration 0.49% Weight Nanoparticles CO(Fe2O4) (0.5g).**

Sandstone (S-006) was used for this scenario, the sample was impressed in nanoparticles fluid CO(Fe2O4) with concentration 0.49 %. As have mentioned in the first scenario, we observed that the penetration of nanoparticle into the sample pores is happened where the recovered oil droplets was coming out of the cores as swelling oil droplets. At the beginning, the oil recovery at room temperature (25°C) for 24 hours was (19.3%), and then increased the temperature to (30°C) for another 24 hours, thus we noticed that a slightly increased in oil recovery to (22.3%). The temperature further increased to reach (50°C) and fixed at (50°C) for 24 hours. Hence, the oil recovery rate was (35.7%). The temperature further increased to reach (70°C) and fixed at (70°C) for 24 hours and the recovery rate was (48.3%) as showing in (Figure 7).

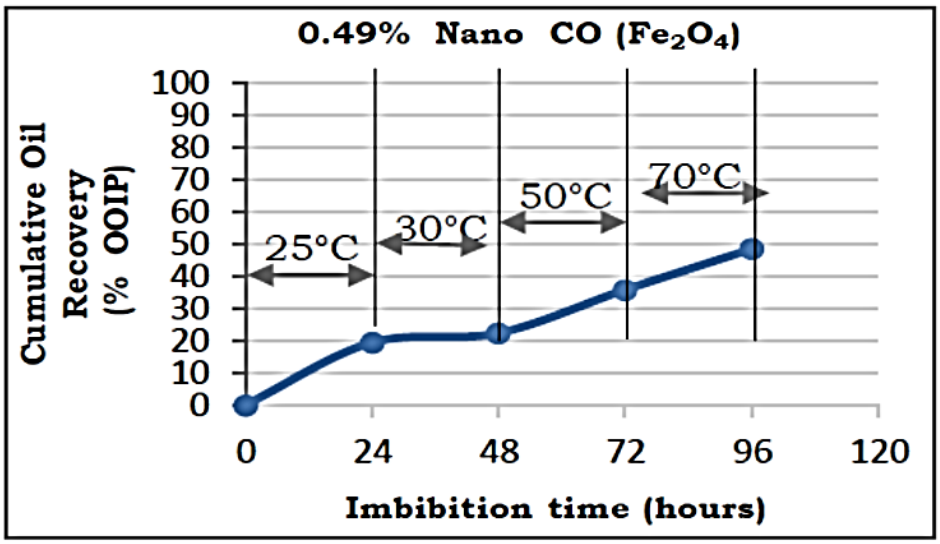

Figure 7. Effect CO(Fe2O4) Conctriction 0.49% on Cumulative Oil Recovery for Sandstone Core Samples

- **2nd Scenario at Concentration 0.99% Weight Nanoparticles CO(Fe2O4) (1g).**

Sandstone (S-003) was used for this scenario, the sample was impressed in nanoparticles fluid CO(Fe2O4) with concentration 0.99%. We observed that the penetration of nanoparticle into the sample pores is happened where the recovered oil droplets was coming out of the cores as swelling oil droplets. At the beginning, the oil recovery at room temperature (25°C) for 24 hours was very low (2.8%), and then increased the temperature to (30°C) for another 24 hours, thus we noticed that a slightly increased in oil recovery to (5.7%). The temperature further increased to reach (50°C) and fixed at (50°C) for 24 hours. Hence, the oil recovery rate was (21.7%). The temperature further increased to reach (70°C) and fixed at (70°C) for 24 hours and the recovery rate was (24%) as showing in (Figure 8).

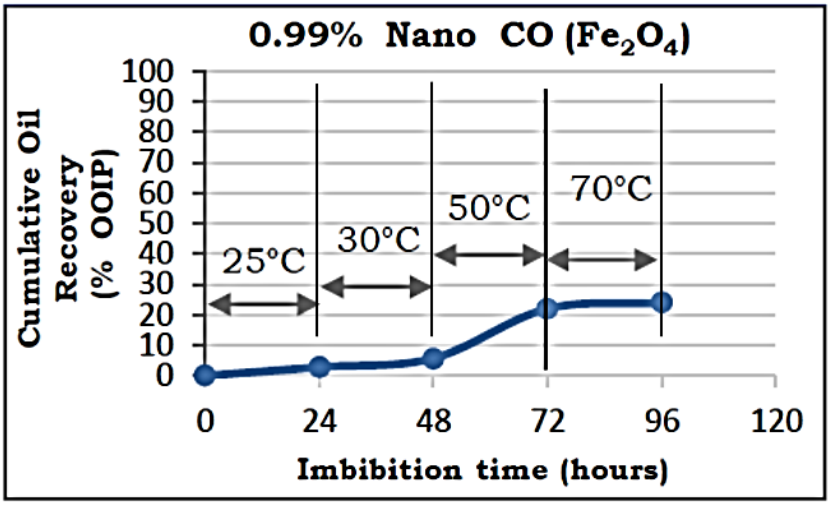

Figure 8. Effect CO(Fe2O4) Conctriction 0.99% on Cumulative Oil Recovery for Sandstone Core Samples

- **3th Scenario at Concentration 1.47% Weight Nanoparticles CO(Fe2O4) (1.5g).**

Sandstone (S-007) was used for this scenario, the sample was impressed in nanoparticles fluid CO(Fe2O4) with concentration 1.47%. Oil swilling was observed as the previous scenarios. At the beginning, the oil recovery at room temperature (25°C) for 24 hours was very (6.7%), and then increased the temperature to (30°C) for another 24 hours, thus we noticed that a slightly increased in oil recovery to (9.5%). The temperature further increased to reach (50°C) and fixed at (50°C) for 24 hours. Hence, the oil recovery rate was (45.0%). The temperature further increased to reach (70°C) and fixed at (70°C) for 24 hours and the recovery rate was (67.6%) as showing in (Figure 9).

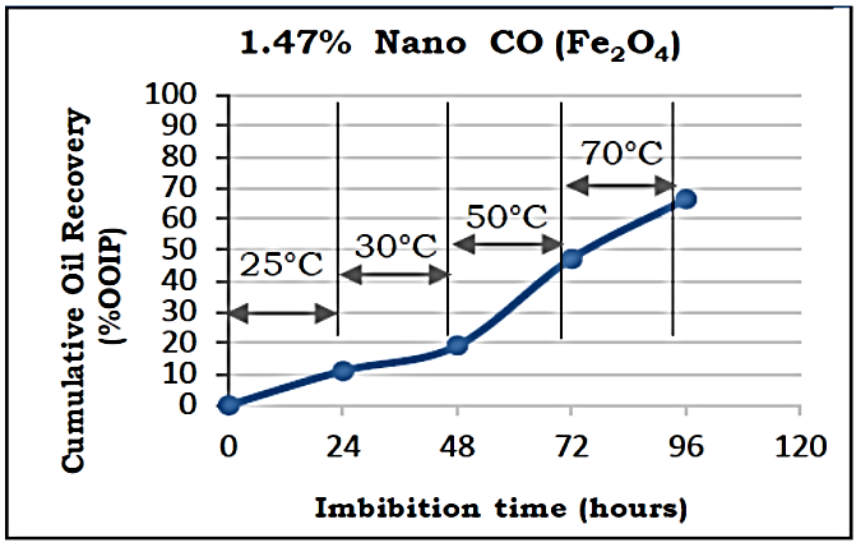

Figure 9. Effect CO(Fe2O4) Conctriction 1.47% on Cumulative Oil Recovery for Sandstone Core Samples

3.4.2 Effect of Distillate Water, With Time, and Temperature on Oil Recovery for core Sample

Sandstone (S-005) was used for this scenario, the sample was impressed in distilled water without changing properties. Oil swelling has not been observed in this case. At the beginning, the oil recovery at room temperature (25°C) for 24 hours was very (13.7%), and then increased the temperature to (30°C) for another 24 hours, thus we noticed that a slightly increased in oil recovery to (20.6%). The temperature further increased to reach (50°C) and fixed at (50°C) for 24 hours. Hence, the oil recovery rate was (57.7%). The temperature further increased to reach (70°C) and fixed at (70°C) for 24 hours and the recovery rate was (90%) as showing in (Figure 10).

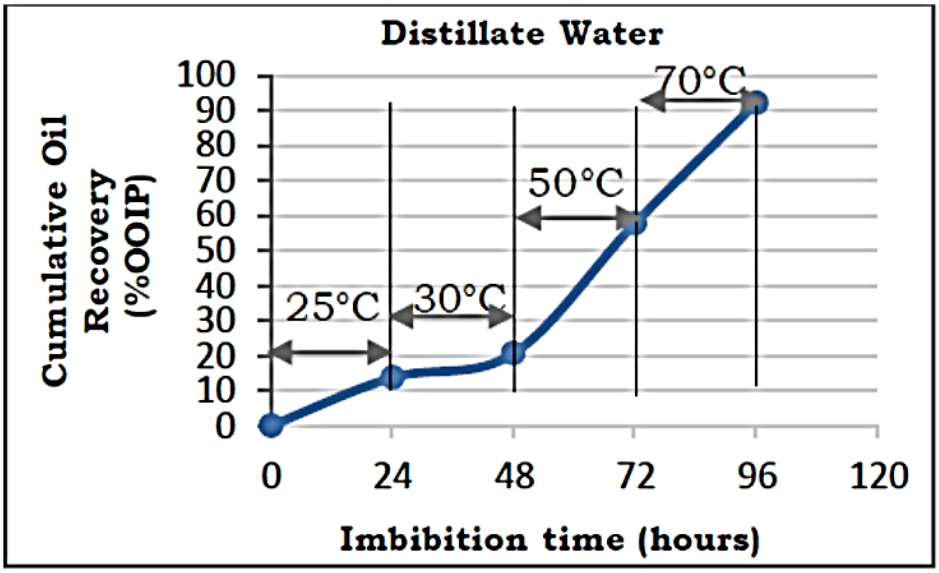

Figure 10. Effect of Distillated Water on Cumulative Oil Recovery for Sandstone Core Samples

The distalled water scenario has given the the highest recovery factor compared with the nanoparticles. thus the high permeability of the cores may be the main reoson for the highest recovery factor in the ditalled water. The penetration of nanoparticle into the sample pores cause the reduce of the permeability of the pores. That may affect the low recovery factor. Whatever, varous tests are currently running at China University of petroleum to deeply investigate the effect of CO (Fe2O4) on the nanoparticles. this work represents the first work about this material but it is not the last.

4. CONCLUSIONS AND RECOMMENDATION

The conclusions reached after this study are:

- The nanoparticles CO (Fe2O4) has been used as chemical nanoparticles to enhance the oil recovery.
- The distilled water gave a high oil recovery factor when it compared with the nanoparticles CO (Fe2O4)
- Oil swelling has been observed during the nanoparticles scenarios.

Recommendations:

- Use various oil density and viscosity to show the CO(Fe2O4) effect on oil recovery.
- Permeability measurements should be done before run the experimental.
- Use various permeability and wettability rock type to show the CO(Fe2O4) effect on oil recovery.

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